Developments in large γ-ray detector arrays

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We have reviewed [1] the development of large γ-ray detector arrays. Gamma-ray spectroscopy was revolutionized by the introduction of high energy-resolution semiconductor germanium (Ge) detectors in the early 60's. This led to the large increase in sensitivity realized by today's arrays of Compton-suppressed Ge detectors. A still larger increase in sensitivity is expected by implementing the new concept of tracking. A tracking array consists of highly segmented Ge detectors (that can cover the full 4π solid angle) in which γ rays will be identified by measuring and tracking every γ-ray interaction.

The starting point of the review was the discovery of Ge semiconductor detectors some 40 years ago. Because of the small band gap between the valence band and the conduction band in the Ge material, the interaction of a γ ray with the detector results in the creation of many electron-hole pairs, giving a high energy-resolution, much higher than that of other existing γ-ray detectors such as scintillators. Later, the availability of high-purity Ge (HPGe) material led to the construction of large-volume detectors (typically 7cmx8cm cylinders). Other important features, such as the use of n-type radiation-damage-resistant material, made possible the development of many-γ-ray-detector arrays for in-beam use.

The first-generation Ge detector arrays were developed in the 80's. There were many around the world and they included 10-20 Compton-suppressed Ge (CSG) detectors. The new feature was the Compton suppression, in which the detection of a γ ray was vetoed if the anti-Compton shield (a very efficient γ-ray cylindrical detector made of bismuth germanate (BGO)) detected a photon that escaped the (relatively small) Ge detector it surrounded. This suppressed by a factor of $\sim$ 2-3 the background from an unwanted γ ray that did not deposit its full energy in the Ge detector.

The second-generation detector arrays were developed in the 90's. They represented the state-of-the-art optimization of a CSG array, using all the available space (4π solid angle) and the biggest Ge detectors available. There are only two such arrays worldwide, Gammasphere in the USA and Euroball in Europe. Gammasphere consists of 110 CSG detectors. At the same time, new concepts emerged which led to an increase in the granularity of the Ge detectors while maintaining, or even increasing, the Ge solid angle: these are the ideas of *composite* and *segmented* detectors. Gammasphere includes 70 2-fold electrically segmented detectors. Euroball, the European counterpart of Gammasphere, includes two types of composite detectors. One type, the cluster detector, uses the new technology of encapsulation for easy handling of individual crystals: each crystal of the cluster is hermetically encased in its own capsule, separate from the cryostat vacuum. The resolving power of the second generation arrays is 100 times higher than that of the first generation arrays.

In a pure Ge array, the removal of the Compton suppressors would increase the Ge solid angle coverage by roughly a factor of two. However, to distinguish between two γ rays detected simultaneously in two detectors and one γ ray interacting in the two detectors, one needs to *track* the interactions of all γ rays in order to identify and separate the emitted γ rays even if several interact in one detector. Taking advantage of the technological advances in segmenting Ge crystals electrically in two dimensions, it is now feasible to build an array of approximately 100 highly segmented Ge detectors. Such an array retains a high efficiency by allowing the *pulse-shape analysis* of signals from each segment to be used to reconstruct the energy and three-dimensional positions of all γ-ray interactions and then track the γ rays.

Presently, such an array, called GRETA (for Gamma-Ray Energy Tracking Array) is being developed at LBNL [2]. It is planned to include 120-130 36-segmented HPGe detectors. A module element consisting of three encapsulated detectors has been ordered. GRETA will have a resolving power 1000 times higher than that of the second-generation arrays and will have entirely new physics capabilities.

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[2] See the three GRETA contributions in this annual report.